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# High-frequency audiometry in the evaluation of critical noise intensity

**R. Bartsch**[1], **H. G. Dieroff**[2], **and C. Brueckner**[1]

[1] Institute of Industrial Medicine of the Friedrich-Schiller-University Jena, Jahnstraße 3, Jena, 6900, GDR
[2] Audiological Department of Clinic of Otological, Laryngological and Rhinological Disease of the Friedrich-Schiller-University Jena, Lessingstraße 2, Jena, 6900, GDR

**Summary.** We investigated a total of 537 subjects (68 men, 469 women) working in the textile industry to ascertain their hearing level in the conventional hearing range as well as in the high-frequency (HF) range. The persons we tested work at three different noise-levels [80–84, 85–89, 90–94 dB (A), measured as $l_{eq}$). The differences in the hearing thresholds between this three groups mentioned were checked by means of discriminant analysis. The first hearing level changes at a noise-level below 90 dB (A) $l_{eq}$ develop mainly in the HF range. In the conventional hearing range, however, the hearing levels remain unchanged even over long exposure times. Noise-induced hearing loss in the conventional range occurs only in the sound level group of 90 to 94 dB (A) $l_{eq}$ without attaining any social importance. The tests show that, if the noise-level 90 dB (A) $l_{eq}$ is not exceeded, no noise-induced hearing impairments involving social hearing loss are to be observed. Thus we assume that an auditory risk criterion of 85 dB (A) $l_{eq}$ is sufficient to prevent hearing loss of any social importance.

**Key words:** Hearing loss, social – Hearing loss, noise-induced – Audiometry – Noise levels – Hearing ranges

## Introduction

The aim of reducing the level of hazardous noise from 90 dB (A) to 85 dB (A) – measured as equivalent continuous noise level ($l_{eq}$) – is to create an acoustic environment that is free from adverse effects on individual health. Audiometry today allows a better understanding of the development of noise-induced hearing loss. With ISO/DIN 1999 we have now more accurate levels of hearing thresholds as a result of ageing. Thus we can better review the noise-induced permanent threshold shift (NIPTS). The rapid development of HF audiometry allows a better examination of the socalled "early" damage of the cochlea or inner ear. The investigation discussed here was designed to determine the level, or better the range of noise-level, within which no effect on the hearing threshold is to be ascertained. We also studied the influence of exposure-time. The persons tested work in three different noise-level groups [80–84, 85–89, 90–94 dB (A) $l_{eq}$]. The first two are of special interest, the third is to be compared with them.

*Offprint requests to:* R. Bartsch

## Methods

As a measuring device we used a conventional audiometer (VEB Präcitronic, Dresden, GDR, model-type MA 31), calibrated according to ISO 368 and a semi-automatic Békésy audiometer of Rudmose Co. (USA), with an HF range of 4 to 18 kHz. For the latter audiometer the original earphones were replaced by a special free field system (Dieroff 1982). Calibration of this device was performed in ten 18- to 20-year-old adults with normal hearing and whose thresholds at the frequencies 4, 6, 8, 10 kHz reached the same level according to ISO 368 calibrated audiometer (Heinicke 1981). We investigated a total of 537 subjects (68 men, 469 women) working in the textile industry at constant noise-levels (spinners, spoolers, weavers).

They were tested as part of routine monitoring. HF-audiometry is voluntary. When we study the usefulness of HF-audiometry, we use only volunteers. Twelve adults had to be excluded from the investigation as they had an air-bone gap of more than 10 dB or middle ear disease. In the figures we used the values of ISO 1999 for women as a control. In the HF range, those of Heinicke (1981) were applied. The differences between the hearing levels at the registered frequencies in the abovementioned noise-level groups were checked for significance by the statistical method of discriminant analysis

**Table 1.** Results of discriminant analysis of hearing threshold from 0.5–18 kHz in special stratified groups. Short- and long-exposed young persons at different noise-levels were compared. The sequence of frequencies (Column 7) determines the importance for the differences of the hearing thresholds

| No. of Analyses | Grouping variables | | | | | Frequencies decisive for separating the thresholds |
|---|---|---|---|---|---|---|
| | Age (years) | Exposure time (years) | Compared noise-level $l_{eq}$ dB(A) | No. of evaluated frequencies | No. of test persons | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | 17–30 | ≤10 | 80–84 | 16 | 216 | 14 kHz<br>10 kHz |
| | 17–30 | ≤10 | 85–90 | 16 | 216 | 12 kHz<br>2 kHz<br>0.5 kHz |
| 2 | 17–30 | ≤20 | 80–84 | 16 | 240 | 14 kHz<br>10 kHz |
| | 17–30 | ≤20 | 85–90 | 16 | 240 | 13 kHz<br>2 kHz<br>0.5 kHz |

(Ahrens and Läuter 1985). This is a method based on the idea that a term like hearing threshold will be described by a multitude of variables, here they are the registered frequencies. In discriminant analysis no multiple mean test is carried out for each variable, but the question is answered whether there is a general difference between the thresholds or not. The statistical program package of BMDP was used to solve the problem.

## Results

At first we classified the hearing-thresholds (measured test frequencies: 0.125 to 10 kHz then 11, 12, 13, 14, 15, 16, and 18 kHz) four-dimensionally with the parameters: age, noise level, exposure time. We think this is necessary since different ages, different exposure times and different noise-levels result in different hearing thresholds. This stratification allows mutual and reciprocal control of two of the three variables in order to study the effects of the third. First we used three noise-level groups, three age groups and three exposure time groups, thus obtaining, after stratification, 27[1] different hearing threshold groups, of course with different numbers of subjects. We often had to extend the lifespan of the age-groups to increase the number of subjects. This resulted in 18 different groups. These groups did not differ significantly in use of ear protection ($P = 0.05$, $\chi^2$-test). The percentage of users was very low. This paper mainly reflects the influence of the variable noise level. Following stratification we get, for every noise-level group, one mean hearing threshold for each measured frequency dependent upon age and exposure time. For example Table 1: in Analysis 1 we study the effect of a higher noise-level. Our stratification program allows us to compare the hearing level of two groups of subjects that are in the same age group (here 17–30 years) and the same exposure time group (here up to 10 years). Under another aspect we can see what happens when the exposure time is prolonged under the same conditions. Analysis 2 shows the results. This is an extension of Analysis 1 with further subjects. We hoped to find the well-known $c^5$-deep registered in Column 7.

The most important questions are:

1. Are these hearing levels significantly different from each other?
2. Which frequencies are responsible for the difference?

In the field of conventional audiometry the answer is well-known, but is it relevant in high-frequency audiometry? The results of discriminant analysis were described in Tables 1 and 2. Table 2 elucidates the same problem as Table 1 but with older persons. Here Analysis 3 is an extension of Analysis 1. As our computer program restricts the number of frequencies if a certain number of subjects is below a given limit we had to restrict ourselves to seven frequencies of HF-hearing range. The number of subjects for analysis is an adjusted number of all possibilities. The computer program uses only cases with complete data and demands a balanced number in every group.

[1] The number "27" results mathematically as variations $n^k$ with $n = 3$, $k = 3$; or $n = 3$, $k = 2$ and multiplied by two (results in 18). Neither all combinations nor all variations are of biological relevance: Nobody can find a 17- to 30-year-old subject, who has been exposed for more than 30 years. This clearly illustrates the limits of these mathematical possibilities. Some other variations include only a very few subjects. Nevertheless they would be interesting for further analysis

**Table 2.** Results of discriminant analysis of the HF hearing threshold (11–18 kHz) in special stratified groups. Compared are long-respectively very long-exposed older persons at different noise-levels. Frequency sequence in Column 7 has the same significance as in Table 1

| No. of Analyses | Grouping variables | | | | | Frequencies decisive for separating the thresholds |
|---|---|---|---|---|---|---|
| | Age (years) | Exposure time (years) | Compared noise-level $l_{eq}$ dB(A) | No. of evaluated frequencies | No. of test persons | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | 31–60 | 11–20 | 80–84 | 7 | 71 | 13 kHz |
| | 31–60 | 11–20 | 85–89 | 7 | 71 | 18 kHz |
| 2 | 31–60 | 21–41 | 80–84 | 7 | 180 | 13 kHz<br>18 kHz |
| | 31–60 | 21–41 | 85–89 | 7 | 180 | 11 kHz<br>16 kHz |
| 3 | 31–60 | ≤20 | 80–84 | 7 | 97 | 13 kHz |
| | 31–60 | ≤20 | 85–89 | 7 | 97 | 18 kHz |

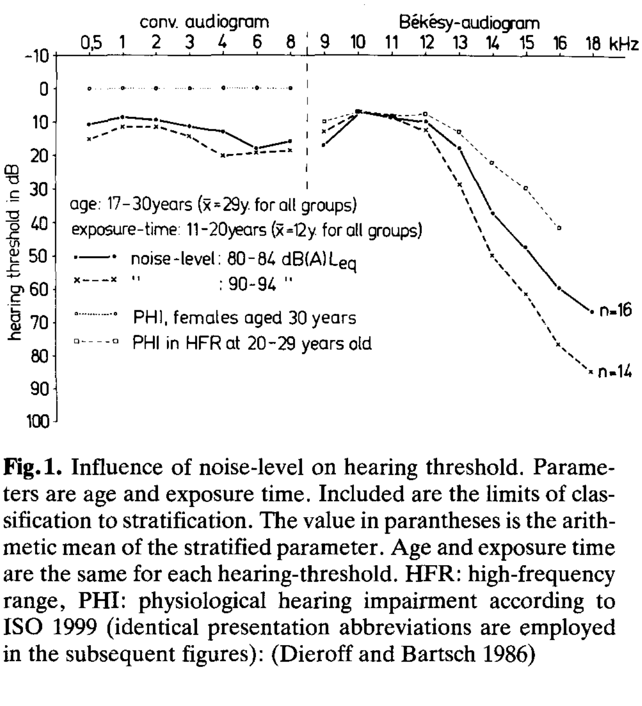


**Fig. 1.** Influence of noise-level on hearing threshold. Parameters are age and exposure time. Included are the limits of classification to stratification. The value in parantheses is the arithmetic mean of the stratified parameter. Age and exposure time are the same for each hearing-threshold. HFR: high-frequency range, PHI: physiological hearing impairment according to ISO 1999 (identical presentation abbreviations are employed in the subsequent figures): (Dieroff and Bartsch 1986)

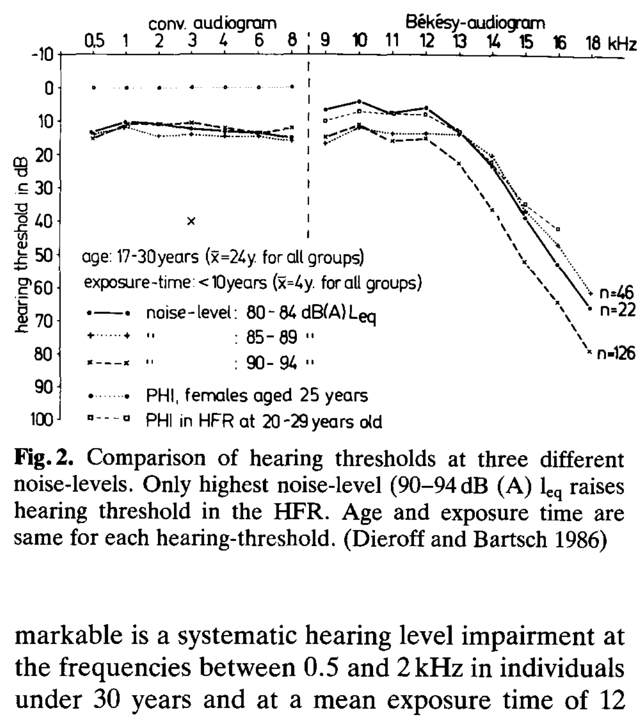


**Fig. 2.** Comparison of hearing thresholds at three different noise-levels. Only highest noise-level (90–94 dB (A) $l_{eq}$ raises hearing threshold in the HFR. Age and exposure time are same for each hearing-threshold. (Dieroff and Bartsch 1986)

For further information see "The user's digest" of BMDP. All hearing thresholds represented in the tables and figures are significantly different. The hearing thresholds of the highest and lowest noise-levels are also significantly different, which is not presented here as it not the objective of this paper. However, the most significant result of fundamental importance is that at noise-levels from 80 to 90 dB (A) $l_{eq}$ the well-known $c^5$-deep or the frequency range between 4 and 6 kHz is not responsible for the difference of the hearing thresholds. On the contrary, we found the first hearing impairment in the hearing-frequency range from 10 to 14 kHz (Table 1 Column 7). Remarkable is a systematic hearing level impairment at the frequencies between 0.5 and 2 kHz in individuals under 30 years and at a mean exposure time of 12 years to the noise-levels mentioned above. We cannot explain this fact, but this impairment is very much smaller than in the high-frequency range. Figure 1 demonstrates that the change in hearing threshold depends on noise-level at an exposure time from 11 to 20 years (mean: 12 years) and young people (17–30 years, mean: 29 years). There is only a small hearing level impairment which is independent of noise-level. This hearing impairment is most significant in the HF range. Figure 2 demonstrates the same comparison for persons with a small exposure time (mean: 4 years) at three different noise-levels. Figures 3 and 4 show the influence of exposure time with a slight increase in age (3 years), which is denoted in

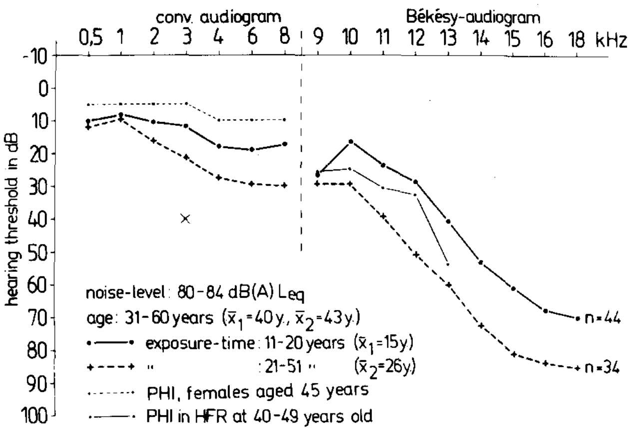


**Fig. 3.** Influence of increasing exposure time at a noise-level of 80–84 dB (A) $l_{eq}$. With increasing exposure time a small threshold elevation developes, especially in the high-frequency range. Here age and exposure time have to differ of course

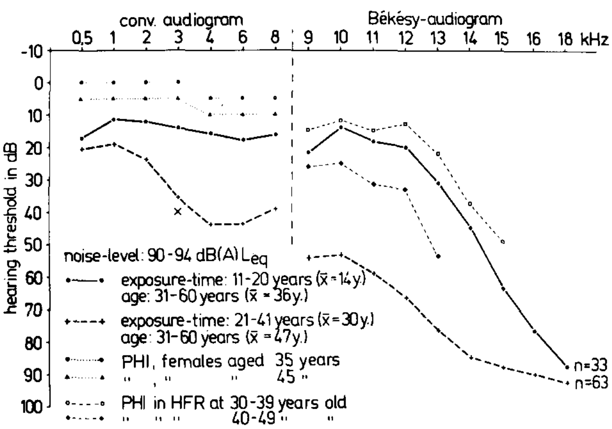


**Fig. 4.** Influence of increasing exposure time at a noise-level of 90–94 dB (A) $l_{eq}$. Increasing exposure time results in a higher threshold, but this approaches a hearing impairment involving social hearing loss. Compare with Fig. 3: here the influence of higher noise-level can be seen

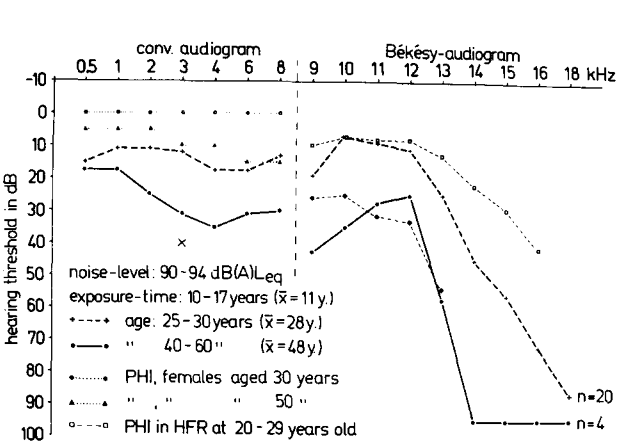


**Fig. 5.** Influence of increasing age at a noise-level of 90–94 dB (A) $l_{eq}$. Increased age at the same exposure time produces a similar degree of threshold impairment as exposure time (see Fig. 4); (Dieroff and Bartsch 1986)

the figures. In spite of obviously prolonged exposure time, there is very little hearing level impairment in the conventional audiometry range; however, there is no hearing impairment of social importance (see Fig. 3). A cross (×) in the figures denotes the controversially discussed point (3 kHz, 40 dB) of hearing impairment which can possibly result in deafness of possible social importance. Figure 4 shows the hearing threshold of people with an average of 30 years exposure time, and an average of 47 years lifetime and noise-level from 90 to 94 dB (A) $l_{eq}$. In this group the hearing threshold nearly reaches the value of possibly social importance. However, it is very interesting that the pattern of noise-induced hearing impairment resembles very closely that resulting from the influence of life-time (Fig. 5).

## Discussion

Investigation of the hearing level of large numbers of subjects results in the problem of data-reduction without losing relevant information. Often authors restrict themselves to one frequency of hearing to overcome difficulties in localising and to detecting significant threshold shifts. The high correlation of neighbouring frequencies allows a markedly smaller number of data. Osterhammel (1979) used the method of correlation-analysis to find out if there are correlations in hearing impairment between 4 kHz and HF hearing. We think the method of correlation analysis is unsuitable for the highly correlated hearing levels of neighbouring hearing frequencies. Under the special circumstances of hearing thresholds, the correlation coefficient decreases with increasing distance of the frequencies.

Verschure et al. (1985) used methods of factor-analysis to reduce parameters. They found that there were correlations between low frequency hearing loss and that of high frequencies only when the hearing loss in the latter had reached a certain value.

This supports our findings that first (and also very clearly) the hearing threshold in the HF range significantly shifted. However, the authors themselves mentioned that factor analysis often results in factors which are not plausible and tried still another way, so-called curve-fitting. We decided on discriminant analysis in connection with variance analysis.

We are interested in changes in the hearing threshold, but not in special frequencies. Mathematically, this means that multidimensional classification and data reduction are necessary to obtain an acceptable description of hearing threshold shifts. On the other hand, the model of discriminant analysis described by Ahrens and Läuter (1985) not only results in demonstrating separability (in our case at hearing thresholds) but also in finding those frequencies which produce the threshold differences. As a result of our investigations we conclude that the range around the 13 kHz frequency is of as decisive importance as is the well-known $c^5$-deep in conventional audiometry.

The problem of critical intensity is very interesting for any regulation. This level would define an exposure condition below which a subject could be exposed without adverse effects. Therefore, Slavin (1955) demanded 80 dB (A) and Glorig (1957) proposed 95 dB (A). Our results clearly demonstrate that only noise-levels at 90 to 94 dB (A) produce a definite hearing threshold shift after more than ten years exposure time. However, the effect of age on HF thresholds is almost identical (Fig. 4 compared with Fig. 5). Therefore, we can assume that, in older subjects (about 47 years of age), evaluation of HF range for NIPTS is not correct as the age-related physiological changes of the hearing threshold in this range are very distinct. These findings explain – we assume – the results of Osterhammel (1979): "HF audiometry cannot be used as an early indicator of the traumatic effect of high intensity noise." On account of the higher age we assume that the physiological damage caused by noise damage is masked. As one can see in Fig. 2, young subjects' hearing threshold shift, after very short exposure times (here 4 years on average) at a noise-level of 90 to 94 dB (A), is demonstrable only in the HF range. In the conventional range there is no change at all in any of the three noise-level ranges.

Our investigations indicate the importance of HF audiometry for early detection of noise-induced hearing threshold shifts – but only for young persons with normal hearing before any noise exposure. Furthermore: we may assume that only noise-levels higher than 90 dB (A) $l_{eq}$ cause hearing damage of social consequence.

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